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TITLE: A TOROIDAL HELICAL QUARTZ FORMING MACHINE

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A TOROIDAL HELICAL QUARTZ-FORMING MACHINE

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Summary

K. W. Hanks and T. R. Cole, Los Alamos Scientific Laboratory, Los Alamos, NM 87545--The Scyllac fusion experimental machine used 10 cm diameter smooth bore discharge tubes formed into a simple toroidal shape prior to 1974. At about that time, it was discovered that a discharge tube was required to follow the convoluted shape of the load coil. A machine was designed and built to form a fused quartz tube with a toroidal shape. The machine will accommodate quartz tubes from 5 cm to 20 cm diameter forming it into a 4 m toroidal radius with a 1-5 cm helical displacement. The machine will also generate a helical shape on a linear tube. Two sets of tubes with different helical radii and wavelengths have been successfully fabricated. The problems encountered with the design and fabrication of this machine will be discussed. A 7-minute color film showing the actual machine in operation will be shown.

The Scyllac fusion experiment (Figure 1) required a helical, toroidal, fused quartz tube with a 10-centimeter outside diameter to be used as the vacuum chamber. The tube shape must follow the helical bore of the magnetic bottle or load coils which is required for plasma equilibrium in the eight meter diameter torus.

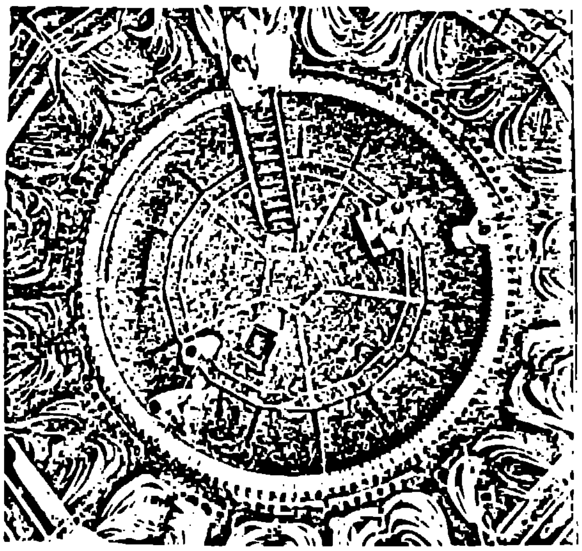


Figure 1

Until 1974 Scyllac had been using simple 10-centimeter diameter toroidal tubes in their experiments. The requirement for toroidal tube with a helical geometry became apparent in order to enhance the confinement of the plasma column. This is illustrated in (Figure 2). The plasma column follows the shape of the flux surface which is machined into the load coil. When the simple toroidal quartz tube was used the plasma was close to the wall of the tube when plasma equilibrium was reached. The best geometry would be to have the plasma centered in the quartz tube at equilibrium. This would require the tube to be toroidal as well as having a helical geometry with a wavelength the same as the machined flux surfaces.

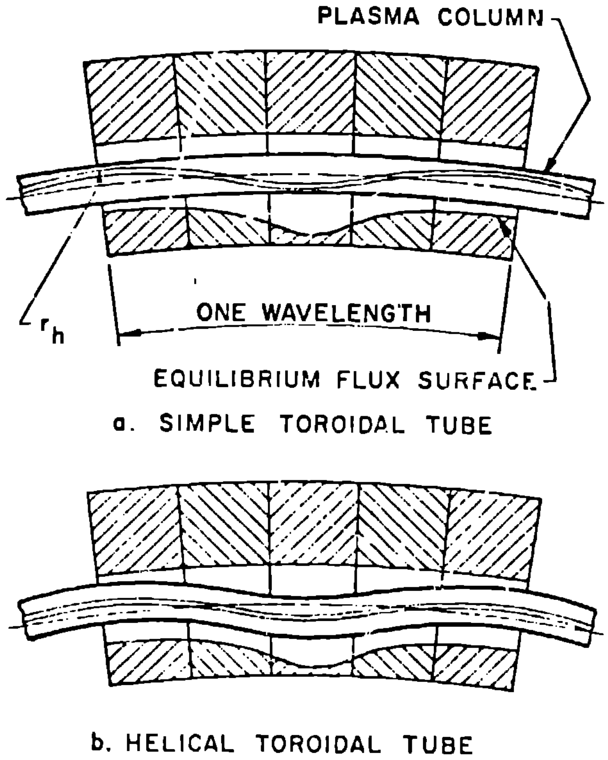
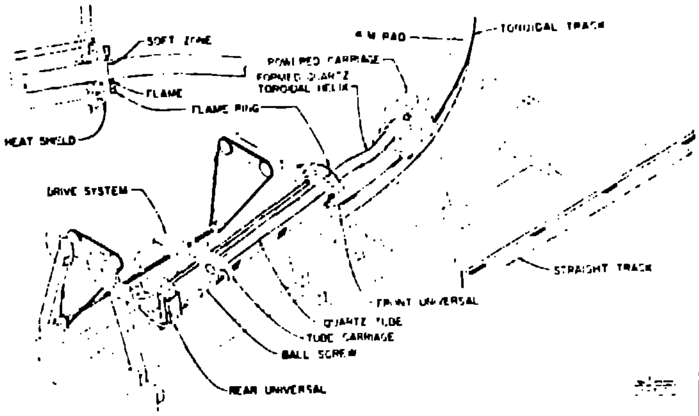


Fig. 2

West German scientists at the Max Planck Institute for Plasma Physics in Garching had a similar need for a helical toroidal quartz tube for their ISAR fusion experiment. They had built a machine to form their tubes and were successful. LASL scientists visited Garching to review and evaluate the German tube forming techniques. With the German information LASL engineers and designers undertook to design a new and more versatile machine. This design is shown in Figure 3. Two universal joints mounted on support arms rotate concurrently about the helical axis each with a different radius. This action results in a cone-shaped movement. The 3 meter long section of straight quartz tube is being fed into a burner positioned near the apex of the cone. The angle α is the tangent angle of the helix to be formed. The straight fused quartz tube is pushed into the burner or flame ring. The formed helical tube is pulled from the burner along a horizontal toroidal track while being held by moving supports which keep the track centerline and the toroidal geometry in alignment.



QUARTZ TUBE FORMING MACHINE

Fig. 3

The machine is designed to form tubes from 5 to 20 centimeter diameter either in a toroidal or straight configuration. A track with the appropriate major radius would have to be installed for each tube radius. Electric stepping motors are used to drive the pull carriage, tube carriage, and rotating arms.

The flame ring is mounted 13 centimeters forward of the front universal and is rotated about its own axis through an arc of approximately 20 degrees so that a uniformly heated hot zone is achieved. The flame ring is shown in Figure 4. The burner contains 72 ports equally spaced on a circle 2 centimeters larger than the quartz tube outside diameter and the ports are tilted 15 degrees toward the front universal so that some pre-heating of the tube occurs. Fused quartz has a relatively high softening temperature (1750°C) and a narrow temperature working range. It solidifies almost instantly when the temperature cools. This narrow temperature working range is the unique property which makes it possible to form the quartz tube. The flame ring is fabricated from copper and has a water jacket on the outside of the ring for cooling. This burner configuration, with a hydrogen-oxygen flame, results in a soft zone on the tube about two millimeters wide.

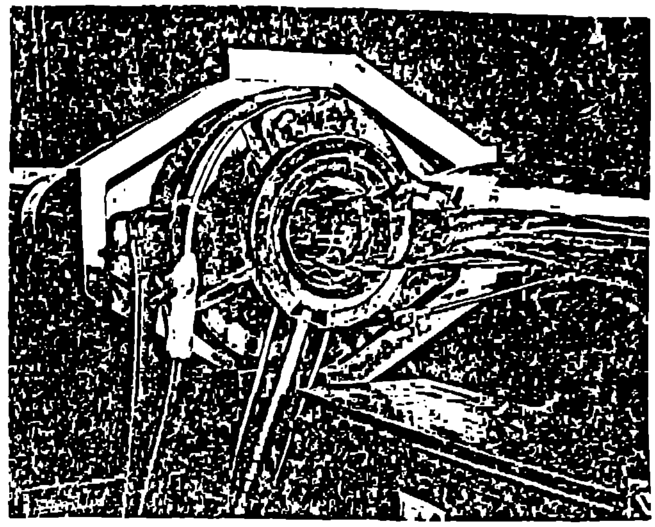


Fig. 4

Cooling of the machine parts near the flame ring was a problem. Because of the 15° tilt of the flame ring to gain pre-heating of the quartz tube most of the heat was directed into the universal. A water cooled stainless steel ring was constructed and mounted between the flame ring and the front universal. Several designs of this cooling ring were tried before an adequate solution was found. Additional cooling was obtained from a cooling channel machined into the backside of the front stainless steel universal immediately adjacent to the tube. The pull carriage, where the tube is clamped, is also water cooled for initial start up when the pull carriage is close to the flame ring.

The final machine is shown in Figure 5 and took 1 and 1/2 years to design, fabricate, assemble, and check-out. The tube being produced has a 10 centimeter outside diameter with a 5 millimeter wall. The helical radius is 3.2 centimeters and the wavelength of the helix is 104.7 centimeters. The helix is being pulled on a 4 meter major radius and two and one-half wavelengths are shown. The first tubes formed on the machine were formed in April 1976 with a helix radius of 1.4 centimeters and a wavelength of 62.8 centimeters. Each 360 degree rotation of the rotating arms produces one wavelength of helical tube and requires 75 minutes to complete. A complete run of approximately three wavelengths requires three hours and 45 minutes to complete.

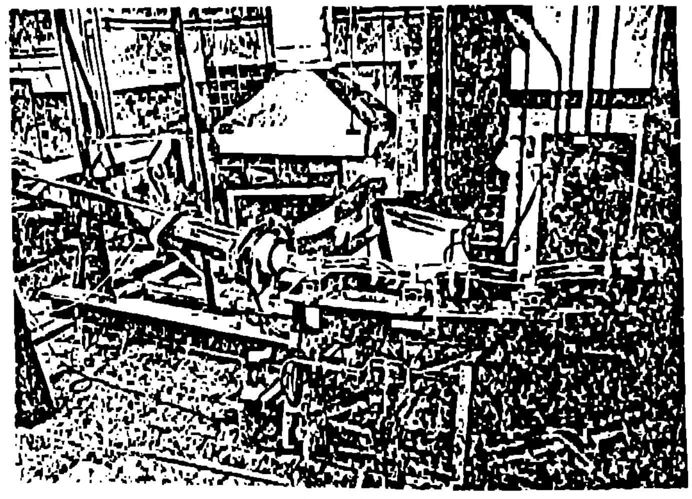


Fig. 5

Figure 6 shows a formed tube adjacent to the bottom half of a set of load coils in which the complicated flux surfaces are machined. The wavelength of the tube and the machined coils match very closely.

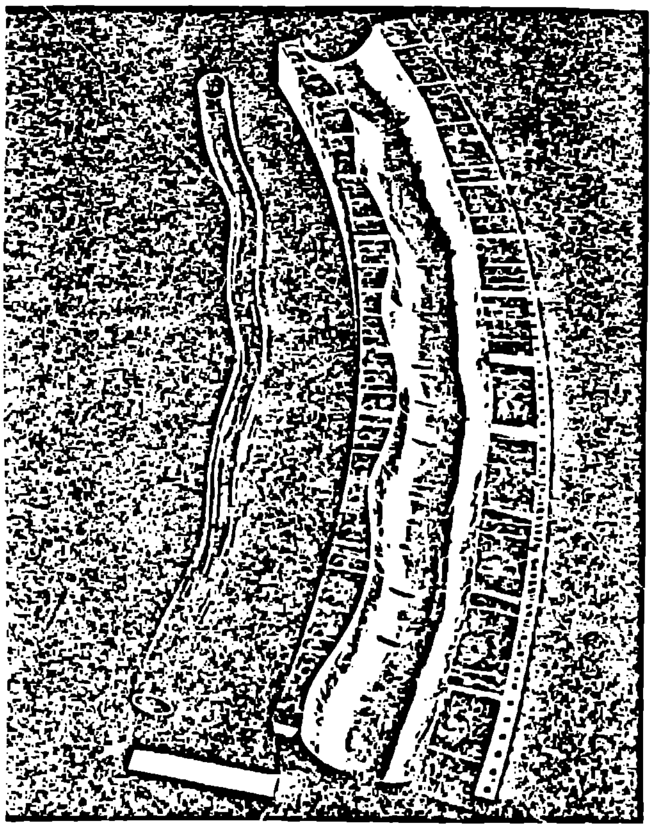


Fig. 6

Since the majority of the diagnostics on the Scyllac device came from the light that the plasma produced, any distortion through the quartz tube wall could affect the accuracy of the light transmission. Optical clarity of the tube, after forming, was determined to be as good as the straight tube stock.

A possible future requirement for LASL CTR experimental devices is to have helical formed tubes with an elliptical cross section. With the experience gained from the present quartz forming machine it is felt that this new requirement could be accomplished.

Figures

1. Scyllac - Plan View
2. Illustrate Need For Tube -- New
3. Machine Isometric
4. Flame Ring Close-up
5. Machine Overview
6. Formed Tube and Set of Bottom Half of Coils